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The design of Main Street reinforced concrete arch over Frisco R. R.

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Department: Civil, Architectural and Environmental Engineering

THESIS

FOR THE

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IN

CIVIL ENGINEERING.

H. ZIRULICK.

SUBJECT:

"The Design of Main Street Reinforced Concrete Arch Over Frisco R. R."

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INTRODUCTION.

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Owing to the cheapness and durability of reinforced concrete, the tendency of the present time in Engineering practice is to build new and replace old structures with reinforced concrete. Therefore, in taking up a subject for a thesis, I have selected, "The Investigation of the Design of a Reinforced Concrete Arch," or, as I named it, "Main Street Reinforced Concrete Arch over Frisco Railroad."

The arch will make an angle of 30° 50' with the Frisco Railroad. It will consist of a single twenty-six foot clear span and have a 14' 4" clear roadway, and have 5' 1" rise or 21 feet above the base of the rail. The arch ring will be one foot thick at the crown and 3 feet at the spring. Loads will be assumed as follows: D.L. 150 lbs. and 120 lbs for live load per square foot.

The reinforcement will consist of two lines of 2-1/3" x 3/4" rods placed two inches from the intradosal and extradosal faces of the arch ring, and spaced at two feet intervals.

The foundation will rest on a dry clay having a safe bearing of 4 tons per square foot.

GENERAL.

The concrete steel design of the present time reaches considerably beyond a simple combination in that the materials are so placed and proportioned that both receive a determined amount of stress dependent upon their relative coefficient of elasticity, so that they are enabled to discharge functions corresponding to the relative capacities of their resistance.

The theory of the composite design is well understood, but involves the value of one quantity whivh has not yet been subjected to a satisfactory empirical determination, and that is the coefficient of elasticity of Portland cement concrete and Portland cement mortar, the estimates of these values ranging from 1,000,000 pounds to perhaps more than 3,000,000 pounds per square inch.

Obviously the coefficient of elasticity of mortar and concrete will depend upon the quality of materials, their age, and the method of treatment in mixing and putting in place. However, by using good qualities of cement and exercising care in treatment in mixing and ramming, we may safely take 1,400,000 lbs. per square inch as the modulus of elasticity of concrete.

SPECIFICATIONS.

CONDITIONS OF CALCULATIONS:

Modulus of elasticity of concrete, 1,400,000 lbs.

Modulus of elasticity of steel, 28,000,000 lbs.

Maxiumu stress per square inch on steel, 10,000 lbs.

Maximum compression per square inch of concrete, 500 lbs.

Maximum tension of concrete, 50 lbs.

The above to be exclusive of temperature stresses. The steel ribs, under a stress not exceeding their elastic limit, must be capable of taking the entire bending moment of the arch without the aid from the concrete.

Dead load 150 lbs. per square foot,

Live load 12 lbs. per square foot.

Temperature 50 F for rise or drop.

PORTLAND CEMENT:

The cement must be of the best quality. Fineness to be such that the cement will all pass through a sieve having 10,000 holes to the square inch, and leave only 10% residue when through a sieve having 14,400 holes to the square inch.

Tensile strength of briquettes of Portland cement which have been gauged, treated and tested to carry an average tensile strength of 175 lbs. per square inch at the expiration of 3 days from gauging, and 500 lbs. at the expiration of 7 days, and have a minimum tensile strength of 600 lbs. after 28 days.

Constancy of Volume. Pats of neat Portland cement one-half inch thick with thin edges, immersed in water after hard set shall show no signs of checking or disintegration.

SAND:

The sand shall be sharp, clean and coarse, and satisfactory to the Engineer.

MORTAR:

The mortar shall be composed of one part Portland cement and two parts sand, well and thoroughly mixed together in a clean box of boards, before the addition of water. It must be used immediately after being mixed; and no mortar left over night. The cement and sand used must at all times be subject to inspection and test of the Engineer.

CONCRETE:

The concrete shall be composed of clean hard broken stone, or gravel, with irregular surface, clean sharp sand, and cement, mixed in the proportion hereafter specified. The cement and sand shall first be thoroughly mixed dry in the proportion specified. The stone, previously drenched with water, shall be added and the mass be thoroughly mixed and turned over until each stone is covered with mortar, and the batch shall be deposited without delay, and be thoroughly rammed until all voids are filled.

The grades of concrete to be used are as follows: For the arches, one part cement, 2 parts sand, 4 parts broken stone or gravel that will pass a one inch ring. For the piers, one part cement, 3 parts sand and 6 parts broken stone that will pass a 2 inch ring. For the foundation, one part cement, 4 parts sand and 8 parts broken stone that will pass a 2 inch ring.

FACING:

Concrete facing shall be used, and shall be composed of one part cement and 2 parts sand, and shall have a thickness of at least one inch on arches and piers and other exposed surfaces.

CONNECTION:

In connecting concrete already set with new concrete, the surface shall be cleaned and roughened, and mopped with a mortar which shall be composed of one part cement to one part sand, to cement the parts together.

ARCHES:

The concrete for the arch shall be started simultaneously from both ends of the arch, and be built in longitudinal sections wide enough to constitute a day's work. The concrete shall be deposited in layers, each layer being well rammed in place before the previously deposited layer has had time to partially set. These sections while being built shall be held in place by substantial timber forms normal to the centering and parallel to each other, and these forms shall be removed when the section has set sufficient to admit of it.

FOUNDATION:

The site for the foundation shall be excavated according to the drawings and be subject to the examination of the engineer and to any change that may be ordered by the engineer.

STEEL RIBS:

Steel ribs shall be imbedded in the concrete of the arch. They shall be spaced at equal distance apart. Each rib shall consist of two flat bars of the size shown on plans. The bars shall be in length of about twenty feet, thoroughly spliced together, and extending into the abutment as shown. Through the center of each bar shall be driven a line of rivets spaced one foot c. to c., with projection about 3/4 inch from each face of bar, except through splice plates where ordinary heads will be used.

The bars shall be in pairs with their centers placed two inches within the inner and outer lines of the arch, respectively, as shown. The area of the cross-section shall not be less than 1/2 square inch. Test pieces from finished material shall have an ultimate strength of from 60,000 to 65,000 pounds per square inch, an elastic limit of not less than one-half of the ultimate. It must bend cold 180 degrees flat on itself, without fracture on outside of bent portion.

CALCULATION.

NOMENCLATURE:

H_l = Horizontal thrust on left support,

M_l = The moment at the left support,

M_x = the moment at any point having coordinates, x & y.

V_l = the vertical reaction at the left support,

l = the span of the arch axis,

f = the rise of the arch axis,

x & y = the coordinates of any point of the arch axis,

ϕ = the angular distance to the left of the crown of any point having the coordinates x & y.

P = Any vertical load.

dx = ds cos ϕ

dy = ds sin ϕ

$\Delta = \frac{ds}{I}$

Σ = sign of summation.

F = area of rib.

E = modulus of elasticity.

p = unit stress in extreme fiber of arch rib.

$N_x = V_x \sin\phi + H_x \cos\phi$ + axial or normal stress.

$M_x = M_l + V_l x - H_l y + P(x-a)$, horizontal load.

$$\frac{M_x}{H_l} = \frac{M_l}{H_l}\,\frac{l-x}{l} + \frac{M\,x}{H_l\,l} - y + \frac{m_x}{H_l} \quad \text{Vertical load.}$$

$$H_1 = \frac{\Sigma m_x A\left(y - \frac{\Sigma y A}{\Sigma A}\right)}{2\Sigma y A\left(y - \frac{\Sigma y A}{\Sigma A}\right)}$$

Where m_x equals the common moment for equal and symmetrically placed loads.

Assuming unit loads the following values of m_x may be written:-

Between the load and the left support,

$$m_x = R_1 x = x \cdot \frac{dx}{2} Z$$

where dx equals length of division into which the span is divided, or l equals to ndx.

Between the first load and the center of the span,

$$M_x = R_1 x - (x-a) = a = \frac{kdx}{2}$$ where dx = length (of division into which the span is divided or l = ndx

$$\text{Then } \Sigma m_x A\left(y - \frac{\Sigma y A}{\Sigma A}\right) = \left(\sum_{x=0}^{x=a} \left(y - \frac{\Sigma y A}{\Sigma A}\right) A + K \sum_{x=a}^{x=\frac{l}{2}} \left(y - \frac{\Sigma y A}{\Sigma A}\right)\frac{dx}{2}\right.$$

$$= \frac{Pdx}{2l} \qquad M_1 = \frac{H_1 \Sigma y A}{\Sigma A} - \left(\frac{\Sigma m_x A}{\Sigma A} + \frac{\Sigma m_x \left(x - \frac{l}{2}\right) A}{\Sigma A\left(\frac{l}{2} - \frac{\Sigma x^2 A}{\Sigma x A}\right)}\right)$$

$\frac{H_1 \Sigma y}{\Sigma A}$ & $\frac{M x A}{\Sigma A}$ are known quantities.

By a process given by Howe, we can reduce

$$\Sigma m_x A\left(x - \frac{1}{2}l\right) = \left[(n-K)\sum_{x=\frac{l}{2}}^{x=a} (z-n) z A - K \sum_{x=A}^{x=\frac{l}{2}} (z-n)^2 A\right] \left(\frac{dx}{2}\right)\frac{1}{n}$$

This expression is long but very easy to use. Similarly the expression

Fiber stress for any section.

$$P = \frac{N_x}{F} \pm \frac{M_x Z}{I} = \frac{N_x}{F} \pm M \; \frac{I}{S}$$

where P = the stress in the outer fiber

N_x = the axial stress or the normal component of the resultant stress upon the section being considered.

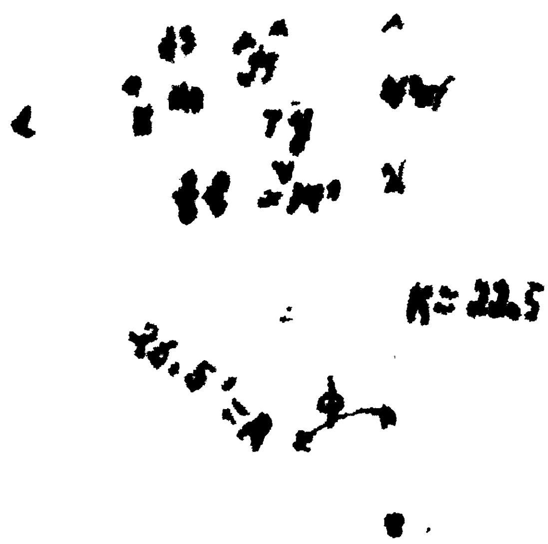
F = the area of the section,

M_x = bending moment of the section.

Z = distance of outer fiber from the neutral axis.

I = the moment of inertia of the section.

S = I/Z = the section modulus.



$$\frac{1}{2} l = \sqrt{R^2 - (R-f)^2}$$

$$\sin \varphi = \frac{l}{2R} = \frac{28}{2x26.5} = 31^\circ \; 53.44'$$

$$\text{Arc AB} = \frac{2\pi R}{360} \, . \, 31.9233 = 15.34$$

$$ds = \frac{15.34}{8} = 1.9185 \text{ feet.}$$

COMPUTATION OF X & Y.

Table I.

Point No.	Ø	sinØ	CosØ	R sinØ	R cosØ	x=28 -RsinØ	y= R cos (Ø-k)
1	29′ 53.85′	.498	.867	13.208	23.073	0.807	0.5733
2	25° 54.69	.438	.899	11.579	23.836	2.421	1.366
3	21° 55.48	.373	.928	9.891	24.583	4.119	2.0837
4	17° 56.31	.308	.951	8.161	25.211	5.838	2.711
5	13° 57.13	.241	.970	6.389	25.718	7.611	3.218
6	9° 57.95	.173	.985	4.593	26.099	9.406	3.599
7	5° 58.77	.104	.995	2.760	26.35	11.240	3.815
8	1° 59.59	.035	.999	.921	26.484	13.079	3.816

COMPUTATION OF Δ

Table II.

Point No.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ds	Δ = ds/[illegible]	y	Δy
1	3.	27.00	2.25	1.3[illegible]	0.3538	2.603	1.9185	0.753	0.573	0.420
2	2.75	20.79	1.73	1.20	0.288	2.018	. . . .	0.947	1.336	1.265
3	2.3	12.167	1.014	0.975	0.191	1.209	. . . .	1.587	2.083	3.307
4	1.6	4.096	0.341	0.53	0.0793	0.427	. . . .	4.552	2.711	12.346
5	1.32	2.299	0.250	0.49	0.048	0.298	. . . .	6.497	3.216	20.75
6	1.15	1.520	0.126	0.405	0.032	0.158	. . . .	12.082	3.599	43.48
7	1.1	1.33	0.11	0.38	0.028	0.138	. . . .	13.930	3.807	52.91
8	1.0	1.0	0.08	0.33	0.022	0.102	. . . .	1[illegible].300	3.816	71.740
								59.138 / 2		206.21 / 2
								= 118.276		= 412.42

$$\_\_\_\_ = \frac{412.42}{118.276} = 3.[illegible]$$

$$H_1 = \frac{\Sigma m_s \Delta \left(y - \frac{\Sigma y \Delta}{\Sigma \Delta}\right)}{2 \Sigma y \Delta \left(y - \frac{\Sigma y \Delta}{\Sigma \Delta}\right)}$$

COMPUTATION FOR H. (Unit Load).

TABLE III.

Point	$y - \frac{\Sigma y\Delta}{\Sigma\Delta}$	B $\Delta\left(y - \frac{\Sigma y\Delta}{\Sigma\Delta}\right)$	C $y\Delta\left(y - \frac{\Sigma y\Delta}{\Sigma\Delta}\right)$		K	ΣB
1	- 3.114	- 2.228	- 1.308	1	1	- 2.228
2	- 2.1[illegible]0	- 2.036	- 2.319	3	3	- 6.108
3	- 1.403	- 2.326	- 4.639	5.1	5.1	-11.762
4	- 0.677	- 3.0[illegible]7	- 8.392	7.23	7.23	-22.39
5	- 0.269	- 1.735	- 5.583	9.4	9.4	-15.309
6	+ 0.112	+ 1.353	+ 4.870	11.7	11.7	+15.830
7	+ 0.32	+ 4.448	+16.930	13.09	13.09	+58.268
8	+ 0.329	+ 6.1[illegible]0	+23.602	16.2	16.2	+100.116
			32.366			
			2			
			65.732			

	$\sum_{x=0}^{x=a} \Sigma B$	$\sum_{x=0}^{x=l/2} KB$	$\sum_{x=0}^{x=l/2} K\Sigma B$	D	$H_1 = \frac{D}{E_c}\frac{dx}{I}$
1	- 2.28	2.228	2.228	0.000	0.0000
2	- 8.336	4.264	12.792	4.456	0.0596
3	- 20.098	6.690	34.039	14.043	0.159
4	- 42.489	9.687	70.639	28.15	0.345
5	- 57.798	11.422	107.366	[illegible]9.568	0.731
6	- 41.968	10.63	124.371	82.603	1.141
7	- 13.700	6.180	80.81	67.19	1.224
8	- 113.816	0.00	0.00	113.816	1.496
					4.745
					2
					9.490

N. B. Table III is divided, seven columns appearing at the top of page and the rest of table underneath.

$$M_1 = \left(H_1 \frac{\Sigma m_x \left(y - \frac{\Sigma yA}{\Sigma A}\right)}{2\Sigma yA\left(y - \frac{\Sigma yA}{\Sigma A}\right)}\right) = \frac{H_1 \Sigma yA}{\Sigma A} = \left(\frac{\Sigma m_x A}{\Sigma A} + \frac{\Sigma m_x (x - l/2) A}{\Sigma A\left(x - \frac{\Sigma x^2 A}{\Sigma A}\right)}\right)$$

Point No.	Z	ZA	$\sum_{x=0}^{x=A} ZA$	$\sum_{x=A}^{x=l/2} A$	K	$\sum_{x=A}^{x=l/2} K\Sigma A$	$\frac{\Sigma m_x A}{.807}$	$\frac{\Sigma m_x A}{\Sigma A}$
1	1	.733	.733	58.405	1	58.405	59.138	.816
2	3	2.843	3.576	57.458	3	175.215	178.791	2.492
3	5.1	8.088	11.664	55.271	5.1	281.882	293.546	4.102
4	7.23	32.96.	43.624	50.709	7.23	366.686	410.350	5.760
5	9.4	60.536	104.16	44.212	9.4	414.728	518.888	7.252
6	11.7	141.336	245.49	32.13	11.7	375.921	621.411	8.694
7	13.09	182.343	427.84	18.80	13.09	559;990	987.88	13.818
8	16.2	304.56	732.40	0.00	16.2	1186.488	1744.987	24.440

$$\frac{dx}{2} = \frac{.807}{2 \times 118.276} = 0.001[illegible]76$$

COMPUTATION OF $\frac{\Sigma m x \Delta (x - \frac{1}{2} l}{\Sigma \Delta (\frac{l}{2} - \frac{\Sigma x^2 \Delta}{\Sigma x \Delta})}$

Point No.	[illegible]	[illegible]	z	[illegible]	[illegible]	[illegible]	[illegible]	$z^2\Delta$
1	15	15	1.	15.	10.995	10.995	164.4	.733
2	13.	13.	3.	39.	36.893	47.9[illegible]	[illegible].8	8.523
3	10.9	10.9	5.1	59.59	73.87	121.865	1329.27	40.277
4	8.77	8.77	7.23	63.41	287.27	409.141	3590.16	238.35
5	6.4	6.4	9.4	60.16	390.469	799.61	5117.5	575.64
6	4.3	4.3	11.7	50.31	517.744	1316.35	5660.3	1653.75
7	2.91	2.91	13.09	38.04	529.897	1846.00	4371.86	2380.98
8	.2	.2	16.2	3.24	60.912	1907.163	381.32	4750.88

Point	$\Sigma Z^2 \Delta$		$-(z-h)^2$	[illegible]	$-\Sigma\Delta(z-h)^2$	$K\Sigma\Delta(z-h)$	[illegible]	[illegible]
1	.733	-225.00	-162.92	1328.22	1328.22	1492.66	0.0218
2	9.256	-169.00	-160.4	1167.78	3503.34	4127.18	0.1527
3	49.533	-118.81	-188.55	979.23	4993.9	6323.19	0.820
4	287.884	- 76.91	-350.86	628.37	4512.6	8182.0	1.029
5	863.58	- 40.96	-266.24	362.13	3409.00	8821.	1.222
6	2517.27	18.49	-236.77	125.36	1642.21	7302.5	0.99
7	4898.82	- 8.46	-117.84	7.52	141.276	4513.13	0.618
8	6949.0	.4	- 7.52	0.00	0.00	381.32	.0521

FINAL COMPUTATION OF M_1 & M_2

Point No.	$\frac{H\Sigma\Delta}{\Sigma A}$	$+ \; \frac{\Sigma MK\Delta}{\Sigma K}$ (M_T)	$\pm$ [illegible]	m_0	M_1	M_2
1	+0	+.316	±.0218	.8378	.7942	-.8378
2	+ .1909	+ 2.492	0.1527	2.644	2.393	-2.45
3	+ .536	+ 4.102	0.826	4.928	3.276	-2.740
4	+1.001	+ 5.760	1.029	6.789	4.731	-5.788
5	+2.548	+ 7.250	1.222	8.470	6.030	+5.83
6	+3.978	+ 8.690	0.9903	9.680	7.700	+5.70
7	+2.563	+13.818	0.618	14.436	13.20	+12.87
8	+5.246	+24.44	0.0521	24.490	19.380	+19.250

M_1 For D.L. & For Location of equilib polygon

POINT No	$y = \frac{M_r M_1}{6}$	Σy	P_m	ΣM_s	M_s	$M_s P_m$	$\frac{[illegible]}{H}$	= equilibrium polygon
1	1.0000	1.0000	6.4	0.0000	- .8378	- 5.337	1.03	below axis.
2	.9169	1.9169	5.6	0.0546	-2.4500	-13.720	0.52	- -
3	.903	2.8199	4.5	0.2086	-2.7401	-12.23	0.31	
4	.8635	3.6834	3.7	0.5536	-5.788	-21.46	0.21	
5	.787	4.4704	3.1	1.2[illegible]6	-5.83	-18.07	0.10	above
6	.658	5.128	2.6	2.4256	+5.700	+14.82	0.07	
7	.654	5.782	2.25	3.2446	12.87	+28.95	0.02	
8	.521	6.243	2.25	4.7456	19.25	+[illegible].15	0.1	below
			30.4		+47.82	+88.18		
			2		-18.64	-70.81		
			60.8		28.18	+17.37		

DL. = 150 x 1.918' = 290 lbs. per square foot.

Max. Fiber stress produced by D.L. at point 1.

$$M_x = M_1 + Vx - H_1 y$$

I = 2.603
x = 0.807
y = 0.573
sin ϕ = 0.498
cos ϕ = 0.867

$$M_x = \underbrace{30.4 \times 290 \times .807}_{Vx} + \underbrace{17.37 \times 290}_{M} - \underbrace{40.49 \times 290 \times .5733}_{Hy}$$

$$M_x = 5423$$

$$N_x = V_1 \sin\phi + H_1 \cos\phi$$

$$N_x = 7114 \times .498 + 6728 \times .867 = 9316$$

$P = \dfrac{N_x}{3.2} \pm .58\ (5423) = 9316$, comp. in lower fiber of concrete,

P = 4022, compression in upper fiber of concrete.

<u>For Steel</u>, $P = \left(\dfrac{N_x}{3.7} \pm .57\ (5423)\right) 20 = 121020$. comp. in lower steel,

P = 80,320, compression in upper steel.

Max. Fiber stress produced by D.L. at point 6.

$$M_x = M_1 + V_1 x - H_1 y - \Sigma P\ (x-a)$$

$$M_x = 5037 + 83420 - 42871 - 4560 = 566$$

$$N_x = (V_1 - \Sigma P)\sin\phi + H_1 \cos\phi$$

$$N_x = 11676$$

$P = \dfrac{11676}{1.35} \pm 1868 = 9820$, comp. in upper fiber of concrete,

P = 6968, compression in lower fiber.

<u>For Steel</u>, P = 200120, compression in upper steel,

P = 145800, compression in lower steel.

Max. Fiber stress at point 8.

$$M_x = M_1 + V_1 x - H_1 y - \Sigma P\ (x-a)$$

$$M_x = 5037 + 65904 - 44659 - 60861 = -34579$$

$Nx = (V_1 - \Sigma P) \sin \phi + H_1 \cos \phi = 11730$

$P = \frac{11730}{1.20} \pm 3.4\ (6086) = -10857$, tension in upper concrete,

$P = 8175$, tension in lower concrete.

<u>For Steel,</u> $P = 217.140$, tension in upper steel,

$P = 160350$, tension in lower steel.

Max. Fiber stress produced by Live Load at point I,

(for loads 1-5, inclusive.)

L.L. = 120 lbs. per sq. ft. = 120 x 1.918 = 230 lbs.

$Mx = M_1 + V_1 x - H_1 y$

$Mx = -18.64 \times 290 + 1.285 \times 290 - 1.47 \times 290$

$Mx = 5405.6 + 372.9 - 1502.5 = -6435$

$Nx = V_1 \sin \phi + H_1 \cos \phi$

$Nx = 372.9 \times .498 + 1302.5 \times .867$

$Nx = 185. + 1128.8 = 1314$

$P = \frac{1314}{3.2} \pm 6435\ (.58)$

= 4442, compression in lower fibre of concrete.

= 2560, tension in upper fibre of concrete.

For the steel, we have,

4442 x 20 = 88,840, compression in lower steel.

2550 x 20 = 51,100, tension in lower steel.

Max. Fiber stress produced by L.L; load at point 6,

Load 1 - 8.

$M_1 = 10540 \times 290 + 5.128 \times 290 \times 3.599 = 2.425 \times 9.4 \times 290$

$= 6608.$

$Nx = 1278$

P = 4900, tension in lower fiber

P = 5300, comp. in tension in upper fiber

For Steel, P = tension = 87880, lower steel

P = tension = 97880.

At Point 6.

P = 11200, tension in upper cohcrete,

P = 9250, tension in lower concrete.

For Steel,

P = 223 60, tension in upper steel,

P = 184590, tension in lower steel.

TABLE

FOR MAXIMUM FIBER STRESSES,

Produced by D. L. and L. L. and Temperature.

D. L. and L. L.

		Concrete		Steel	
Point	**Loads**	Lower	Upper	Lower	Upper
1	D. L.	+6056	+4022	+1[illegible]	+80.320
	L. L. 1-5	+4442	-2560	+ 88,840	-51,100
	6-8	-7459	+5541	-146,360	+168,060
Max. Comp.		10498	9563	209,860	248,380
" ten.		7459	2560	146,360	51,100

		Concrete		Steel	
Point	Loads	Lower	Upper	Lower	Upper
6	D. L.	+6968	+9820	+1[illegible],800	+200,120
	L. L.	-4900	-5300	-87,880	- 97,880

		Concrete		Steel	
Point	Loads	Lower	Upper	Lower	Upper
8	D. L.	-8175	-10,875	-217,140	-160,350
	L. L.	-9250	-11,200	-184,590	-223,960
Max. Comp.		0.00	0.00	0.00	0.00
" **Ten.**		17,425	22,075	401,730	-384,310

Temperature Stresses for Drop of 50° F.

	Concrete		Steel		
Point	Lower	Upper	Lower	Upper	Remark
1	**+5841**	**-6006**	**+116,750**	**-120,020**	**A rise of 50°F**
6	**+6125**	**-6785**	**+122,400**	**-135,600**	**will reverse the**
8	**+6585**	**-7535**	**+131,220**	**-150,480**	**above conditions**

MAXIMUM STRESSES

PProduced by D. L. and L. L. and Temperature.

Point	Concrete Lower	Concrete Upper	Steel Lower	Steel Upper
1	+16339	+ [illegible]	+ 326610	+248380
	-7469	- 8866	- 146360	-[illegible]
6	+13093	+9820	+2682000	+200120
	-4900	-13088	- 87660	-[illegible]
8	+ 6535	+ 00	+ 131220	+ 0.00
	-17425	-29610	- 401730	-534790

+ Compression

\- Tension

The allowable comp. in the concrete when temperature is considered, may be assumed at 500 x 144 = 72,000 lbs. per square foot, and tension 50 x 144 = 7,200 lbs. per square foot. In compression the maximum stresses are considerably less than the allowable, while in tension they are much larger, but the above stresses are less than the ultimate strength of the material, and it is not probable that all the maximum stresses will happen at one time, but if such should be the case, then we have the steel to cover the contingency.

TEMPERATURE STRESSES.

$$Ht = \frac{et^{\circ} \; E \, l}{\Sigma y \cdot \left(\Sigma y - \frac{\Sigma y \Delta}{\Sigma \Delta}\right)}$$

For drop of 50° F., the character of stress will be reversed for rise of 50° F.

E = 1,400,000

e = 0,0000055

t = 50° F.

l = 28'

$$\Sigma y \left(y - \frac{\Sigma y \Delta}{\Sigma \Delta}\right) = 65,732$$

For Point 1,

$$Ht = \frac{0,0000055 \times 28 \times 1,400,000}{65,732} = 3279.$$

$$Mx = 3279 \left(y - \frac{\Sigma y \Delta}{\Sigma \Delta}\right) = 3279 \times 3.114 = -10210.8$$

$$Nx = 3279 \cos \phi = 3279 \times .867 = 2642.8$$

$P = \frac{2642.8}{3.2} \pm 10210 \times (.58) = 6006.$ tension in upper fiber of concrete.

P = 5841.6, comp. in lower fiber of concrete.

For Steel,

P = 120,020, tension in upper steel,

P = 116750, comp. in lower steel.

For Point 6,

P = 6785, tension in upper concrete,

P = 6125, comp. in lower concrete.

For Steel,

P = 135600, tension in upper steel,

P = 122400, comp. in lower steel.

For Point 8,

P = 7535, tension in upper concrete,

P = 6585, comp. in lower concrete.

For Steel,

P = 150480, tension in upper steel,

P = 131220, comp. in lower steel.

Assuming that the steel resists the entire bending moment due to change of temperature, we have:

At Point 1,

Maximum comp. in upper steel due to D.L. and L.L. = 1725 /sq.in.

"	"	" concrete	=	70 lbs. /sq. in.
"	"	lower steel	=	1457 lbs. /sq. in.
"	"	concrete	=	67 lbs. /sq. in.

Moment due to 50°F. = ± 10210 ft. lbs.

Area of steel = 1/2 (3/4 (2-3/8 -3/4)) = .61

Total stress in steel = $\frac{10210}{2.66}$ = 3848. lbs.

Stress per sq. inch = $\frac{3848}{.61}$ = 6341

Maximum comp. = 6341 + 1725 + 70 = 8156

Maximum tension = 6341 + 1014 + 52 = 7407

At Point 6,

Maximum compression = 9560

Maximum tension = 8125

At Point 8,

Maximum tension = 12955

all well within the elastic limit of steel.

ESTIMATES

BILL OF MATERIALS.

Concrete.

	Cement Bbls.	Sand cu.yds.	Stone cu.yds.	Proportion	Concrete cu.yds.
Foundation	30.654	18.98	37.33	1-4-8	39.3
Piers	97.92	45.12	89.28	1-3-6	96.0
Arches	55.67	16.78	35.93	1-2-4	38.125
Parapet	87.60	26.49	53.4	1-2-4	60.0
Total	271.844	107.37	215.94		233.425

Steel.

32 splice plates	2' x 2-5/8" x 5/8" =	353.5 lbs.
32 bars	16' x 2-3/8" x 5/8" =	2828.0 lbs.
32 bars	18' x 2-3/8" x 5/8" =	3181.5 lbs.
512 r	2-1/2" x 3/4" =	430.0 lbs.
Total weight	=	6793.0 lbs.

Pavement, macadam, - - - - - - - - - - - 574 sq. ft.

Excavation, for foundation, - - - - - - 20 cu. yds.

ESTIMATE OF MATERIALS

Material	Amount of Material	Price	Amount
Concrete	233.42 cu.yds.	$ 7.00 per cu.yd.	$ 1,[illegible]
Pavement	574.00 sq. ft.	0.14 " sq. ft.	80.36
Excavation	20.00 cu. yds.	1.20 " cu. yd.	24.00
Steel Bars and Splice plates	6363.00 lbs.	0.05 " lb.	318.15
Rivets	430.00 "	0.08 " "	34.40
Forms for Arches and Parapets.	98.125 cu.yds.	6.50 " cu. yd.	637.81
Total cost, - - - - - - - - - - - - - - - - - - -			$ 2,728.66